Nail Dynamization for Delayed Union and Nonunion in Femur and Tibia Fractures

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abstract

Femoral and tibial shaft fractures are common injuries in the United States. Since their introduction, reamed intramedullary nails have become the treatment of choice for most of these fractures. However, delayed union and nonunion can complicate treatment in up to 10% of patients. Removal of interlocking screws, or dynamization, can promote fracture healing in cases of delayed union or nonunion. The efficacy of nail dynamization has been reported to range from 19% to 82%. This study was conducted to evaluate the efficacy of dynamization, identify the factors associated with its success or failure, and analyze the cost compared with exchange nailing. The authors retrospectively reviewed charts from 2011 to 2014 and searched billing records for Current Procedural Terminology codes 27506 and 27759, for intramedullary nailing of femoral and tibial shaft fractures, and code 20680, for removal of deep hardware. This search identified 34 patients with 35 fractures treated with dynamization for delayed union or nonunion. Dynamization was effective in creating union in 54% of patients. The factor that best correlated with the success of dynamization was the diameter of the fracture callus at the time of dynamization. Direct costs associated with dynamization were nearly $10,000 less than those associated with exchange nailing. Dynamization can be an effective first-line treatment for delayed union and nonunion of femoral and tibial shaft fractures. The union rate in the current study is similar to previously published rates, and cost data suggest that dynamization is a viable alternative to exchange nailing for some patients with delayed union or nonunion. [*Orthopedics*. 2016; 39(6):e1117-e1123.]

Femoral and tibial shaft fractures are commonly encountered by orthopedic surgeons. Since their introduction, reamed intramedullary nails have become the treatment of choice for the majority of these fractures. Rates of union in both femoral and tibial shaft fractures have been reported to range from 90% to 100% with the use of intramedullary nails.[1-6] Despite improved treatment and union rates, problems with delayed union and nonunion continue to occur. Treatment options for delayed union and nonunion include nail dynamization, bone grafting, exchange nailing, compression plating, external fixation, and amputation. Although the treatment algorithm differs in each case, nail dynamization can be a quick, cost-saving, and effective method to promote healing. Nail dynamization is defined as the removal of interlocking screws either proximal or distal to the fracture site to permit bony compression at the fracture site. In the past,

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Table 1

Summary of Previous Studies

Study (Year)	No. Femur	No. Tibia	Indications	Timing of Dynamization	Success Rate
Chalidis et al[4] (2009)	0	22	Nonunions initially treated with intramedullary nailing	Minimum 10-12 wk postoperatively	82%
Wu[9] (1997)	24	0	Delayed healing; sparse callus formation	Minimum 4 mo (range, 5-10 mo)	58%
Pihlajamäki et al[17] (2002)	17	0	Delayed healing; sparse callus formation	Minimum 4 mo (range, 5-10 mo)	24%
Wu and Chen[12] (1997)	12	0	Delayed healing; sparse callus formation	Minimum 4 mo; sparse callus formation	42%
Tigani et al[10] (2005)	75	0	Did not specify	Mean 86 d; sparse callus formation	99%
Wu and Shih[11] (1993)	11	11	Delayed healing; sparse callus formation	Mean 7.8 mo	54%

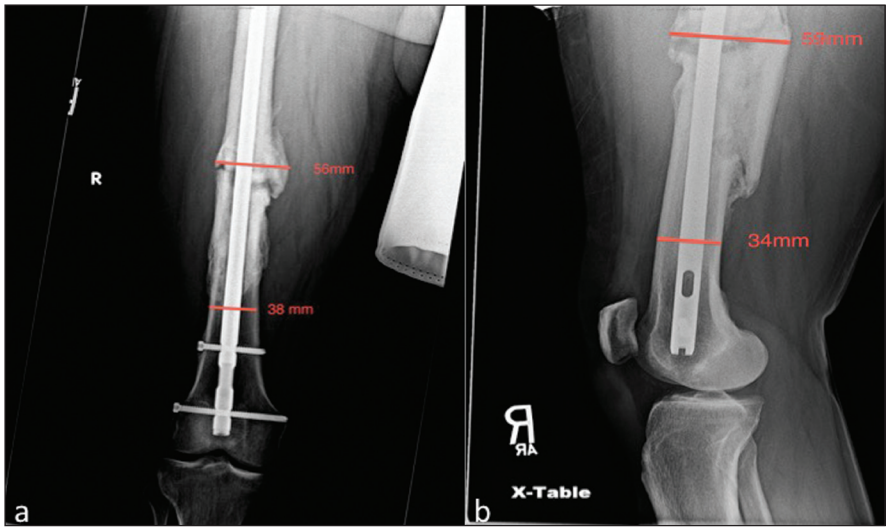

Figure 1: Anteroposterior (a) and lateral (b) radiographs of nonunion of a right femur fracture before dynamization. Both figures show measurements of callus diameter and diaphysis diameter that are used to determine the callus-to-diaphysis ratio.

nail dynamization was routinely performed for all statically locked nails 2 to 4 months after the index surgery.[5,7] Further studies showed that this practice was unnecessary to achieve union in the majority of cases, and it subsequently fell out of favor as standard practice.[8-10] Previous studies of the efficacy of nail dynamization to promote fracture healing reported varying results, with some authors finding dynamization to be effective and others reporting a low rate of success and unacceptable fracture shortening. Previous rates of successful healing after dynamization ranged from 19% to 82%.[4,9,11-15] However, these studies used varying treatment algorithms for the timing of dynamization, postoperative weight bearing, and indications for dynamization. The findings are summarized in **Table 1**. Most studies included 10 to 20 patients and examined different proportions of femoral and tibial fractures, making meaningful interpretation of the data difficult.

The goal of this study was to define the efficacy of nail dynamization for the treatment of femoral shaft and tibial delayed union and nonunion. In the case of failed dynamization, the authors sought to identify risk factors for failure that were not identified in previous studies.

Materials and Methods

Data Collection

Institutional review board approval was obtained. The authors retrospectively reviewed charts between 2011 and 2014 with Current Procedural Terminology codes 27506 and 27759, for intramedullary nailing of tibial and femoral shaft fractures, and code 20680, for removal of deep hardware, to identify patients who were treated with nail dynamization. Patient charts were reviewed to identify the following: mechanism of injury, open or closed fracture, fracture pattern, associated injuries, medical comorbidities, smoking status, medication use, time to dynamization from index surgery, and time from dynamization to successful healing or secondary procedure. Diameter of the fracture callus was also measured at the time of dynamization and compared with the diameter of the normal diaphyseal bone. This technique is shown in **Figure 1**.

Union was defined as no pain at the fracture site, no pain with weight bearing on the affected extremity, and osseous bridging of at least 1 cortex on follow-up radiographs. Examples of tibia and femur fractures before and after dynamization are shown in **Figures 2-5**.

Surgical Management

All operations were performed at the same institution by the orthopedic trauma service. Timing to dynamization was left

to the discretion of the treating surgeon. Infection workup was also at the discretion of the surgeon. All patients with infection were excluded from the study. Screw removal for dynamization was performed as an outpatient procedure, and patients were allowed to bear weight as tolerated at the first follow-up visit.

Results

In total, this study identified 35 fractures in 34 patients who had been treated with nail dynamization for delayed union or nonunion at the authors' institution within the defined study period. The group included 19 patients with 19 femur fractures and 15 patients with 16 tibia fractures. Most of the patients in the study were male (70%), and average age at the time of injury was 40.91 years (range, 16-83 years). Patients underwent dynamization of the fractures, on average, 6.4 months after index surgery (range, 1-13 months). Demographics and details of the patients are shown in **Table 2**.

Time to fracture union occurred an average of 4.8 months after dynamization (range, 3-11 months). Dynamization was successful in 19 of 35 patients (54%). Failed dynamization (46%) occurred when a patient required a secondary procedure for union, such as bone grafting or exchange nailing after dynamization, or when persistent pain occurred with weight bearing.

Analysis of factors that correlated with successful dynamization showed that the diameter of the callus compared with the diaphysis at the time of dynamization was predictive of eventual healing in men. The ideal callus-to-diaphysis ratio was 1.17:1, which allowed for sensitivity and specificity of 81% in predicting healing after dynamization, as seen in **Figure 6**. Preoperative radiographs with a callus-to-diaphysis ratio of greater than 1.17:1 had a 93% rate of union (13 of 14 patients). Patients with a callus diameter of less than 1.17 had a healing rate of only 20% (2 of 10 patients) after dynamization. These findings are summarized in **Figure 7**. Although callus diameter in men was the best predictor of the success of nail dynamization, open fracture at the time of injury correlated with dynamization failure in men. Healing with dynamization after an open

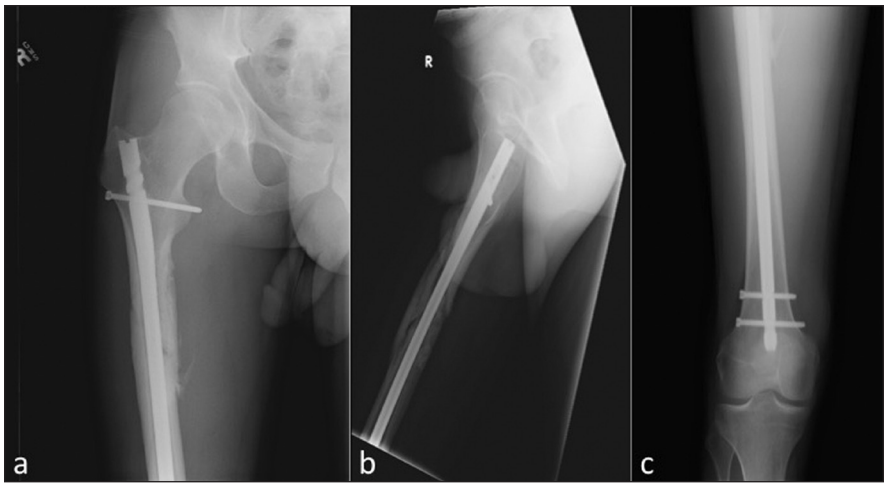

Figure 2: Anteroposterior radiograph of the proximal femur (a) and lateral (b) and anteroposterior (c) radiographs of the distal femur showing femur fracture without evidence of healing in a 30-year-old man with continued pain with weight bearing 7 months after his leg was crushed by a forklift.

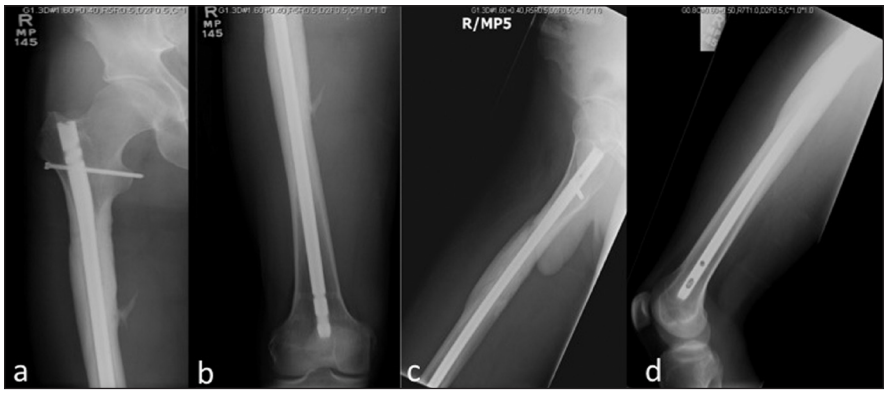

Figure 3: Anteroposterior (a, b) and lateral (c, d) radiographs of the same patient as in Figure 2 obtained 3 months after dynamization showing interval healing and callus formation.

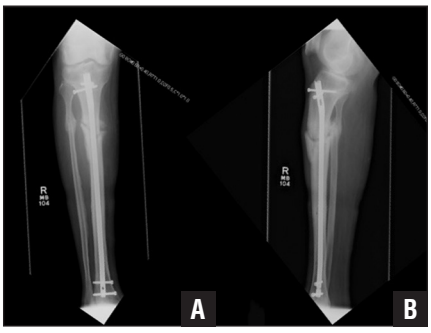

Figure 4: Anteroposterior (A) and lateral (B) radiographs showing nonunion of a tibial shaft fracture in a 74-year-old man 6 months after he was struck by an automobile while walking.

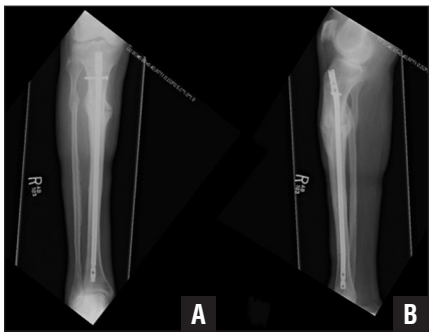

Figure 5: Anteroposterior (A) and lateral (B) radiographs of the same patient as in Figure 4 showing abundant callus formation and healing of the fracture 5 months after dynamization.

Table 2

Patient Characteristics

Patient No./ Sex/Age, y	Bone Diameter, mm	Callus Diameter, mm	Ratio, Callus to Bone	Healed	Pathologic Fracture/ Low Energy	Open Fracture	Nonsteroidal Anti-inflammatory Drugs/Aspirin	Alcohol Abuse	Smoker	Systemic Medical Comorbidities	Time to Dynamization, mo
1/F/29	28	30	1.07	Yes	No	Yes	No	No	No	Yes	6
2/M/30	34	46	1.35	Yes	No	No	Yes	No	No	No	7
3/M/57	31	56	1.81	Yes	No	No	Yes	No	Yes	Yes	9
4/F/41	26	33	1.27	Yes	No	No	No	No	No	Yes	5
5/F/28	28	37	1.32	Yes	No	No	No	Yes	No	No	12
6/M/32	25	39	1.56	Yes	No	No	Yes	Yes	No	No	6
7/M/21	22	31	1.41	Yes	No	Yes	No	No	No	Yes	5
8/M/66	29	35	1.21	Yes	No	No	Yes	No	No	No	6
9/M/35	26	33	1.27	Yes	No	Yes	No	No	No	No	4
10/M/29	34	36	1.06	Yes	No	No	No	No	No	No	1
11/M/16	26	29	1.12	Yes	No	Yes	No	No	No	No	9
12/M/32	32	59	1.84	Yes	No	No	No	No	No	No	5
13/M/74	31	54	1.74	Yes	No	No	Yes	No	No	No	6
14/M/24	30	37	1.23	Yes	No	Yes	No	No	No	No	84
15/M/24	37	47	1.27	Yes	No	Yes	No	No	No	No	3
16/M/83	34	48	1.41	Yes	Yes	No	Yes	No	No	Yes	4
17/M/68	40	57	1.43	Yes	No	No	No	No	No	Yes	7
18/M/32	22	35	1.59	Yes	No	No	Yes	Yes	No	No	6
19/M/30	38	63	1.66	Yes	No	No	No	No	Yes	No	7
20/F/27	33	46	1.39	No	No	Yes	No	No	No	Yes	12
21/M/25	32	32	1.00	No	No	No	No	No	No	No	8
22/F/67	44	47	1.07	No	Yes	No	Yes	No	No	Yes	7
23/F/79	29	37	1.28	No	Yes	No	No	Yes	Yes	Yes	8
24/M/27	30	27	0.90	No	No	Yes	No	No	No	No	5
25/M/62	28	27	0.96	No	No	Yes	Yes	No	No	Yes	5
26/F/29	30	47	1.57	No	No	Yes	No	No	No	Yes	6
27/M/39	29	27	0.93	No	No	Yes	No	Yes	No	Yes	7
28/M/56	36	37	1.03	No	No	Yes	Yes	No	No	No	4
29/M/17	29	34	1.17	No	No	No	No	No	No	No	13
30/F/55	32	37	1.16	No	Yes	No	No	No	No	Yes	6

Table 2 (cont'd)

Patient Characteristics											
Patient No./ Sex/Age, y	Bone Diameter, mm	Callus Diameter, mm	Ratio, Callus to Bone	Healed	Pathologic Fracture/ Low Energy	Open Fracture	Nonsteroidal Anti-inflammatory Drugs/Aspirin	Alcohol Abuse	Smoker	Systemic Medical Comorbidities	Time to Dynamization, mo
31/M/48	21	23	1.10	No	No	Yes	No	No	No	No	5
32/F/49	36	36	1.00	No	Yes	Yes	Yes	No	No	Yes	7
33/M/26	29	33	1.14	No	No	Yes	No	No	No	No	11
34/M/39	25	32	1.28	No	No	Yes	No	No	Yes	No	6
35/F/19	25	29	1.16	No	No	Yes	Yes	No	No	No	7

Abbreviations: F, female; M, male.

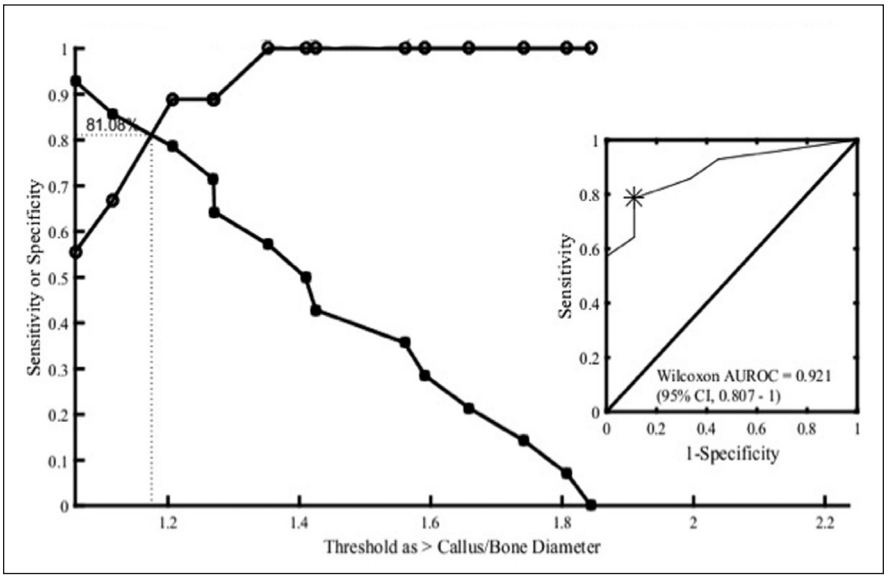

Figure 6: Predicting bone healing after dynamization with callus-to-bone diameter ratio in men. The graph shows sensitivity (closed circles-inferior line) and specificity (open circles-superior line) for different callus-to-bone diameter ratios. These values are optimized at a ratio of 1.17:1. Abbreviations: AUROC, area under the received operating characteristic; CI, confidence interval.

fracture had a negative odds ratio of 0.114 (P=.0295). The authors considered several other patient factors and surgical variables to determine whether any were predictive of successful nail dynamization. Smoking, medical comorbidities, fracture pattern, associated injuries, time to dynamization, and distraction at the fracture site did not correlate with success or failure of dynamization. When data were analyzed separately, no differences were found between femurs and tibias.

Callus diameter and open fractures were factors in predicting the success or failure of nail dynamization in male patients, but these factors were not predictive in female patients. This finding is likely related to the fact that the female population had a high proportion of pathologic fractures (4 of 10 in female patients vs 1 of 24 in male patients). When these pathologic fractures were excluded, analysis of the remaining 6 female patients did not have sufficient power to show factors that predicted the success or failure of dynamization. Although it seems unlikely that men's and women's bones would have different healing potential after dynamization, the current study does not allow any meaningful conclusions about the women included in the study.

Direct cost data also were analyzed. Direct costs associated with the nail dynamization procedure were on average $2463 (range, $927-$12,664). Notably, the patient with the highest direct cost associated with the dynamization procedure underwent a contralateral exchange nail procedure at the same time. When that patient was excluded, the average direct cost of dynamization was $2154 (range, $927-$6015). In this study, 8 patients underwent exchange nailing after dynamization failed. Direct costs of exchange nailing were on average $12,264 (range, $7559-$29,517).

Discussion

Dynamization is an option when treating delayed union and nonunion of the femur or tibia. Although the tibia and femur have significantly different physical and biologic healing environments, dynamization is a first-line treatment for delayed union or nonunion of both, and dynamization causes increased compression at the

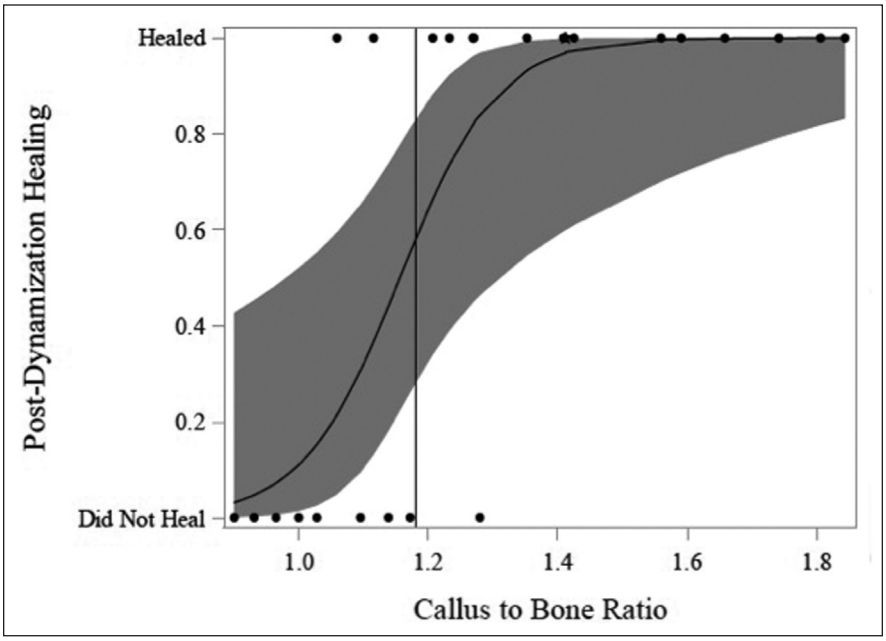

Figure 7: The probability of healing increases with the callus-to-adjacent bone ratio in men. The optimum callus-to-bone ratio for fracture healing after dynamization in men is 1.17:1.

fracture site without interrupting the biology of a healing fracture.

Removal of interlocking screws offers a variety of benefits that promote fracture healing. Dynamization results in increased contact area at the fracture site, improved osteogenesis, and improved transmission of weight-bearing forces.[14,16] These benefits, in addition to the low morbidity of this procedure, its ease of use, and its reduced cost, make it an appealing option compared with bone grafting, exchange nailing, and compression plating. Although dynamization was once routinely performed to help promote fracture healing, it is now performed selectively.[10,15] There are several reasons for this change. First, routine dynamization was found to be unnecessary for fracture healing, and it is associated with a risk of shortening, particularly in spiral and long oblique fractures. In 1997, Wu[9] studied the efficacy of dynamization in 24 cases of femoral delayed union and nonunion. They found a rate of success similar to that of the current study, at 58%, and also noted a greater than 20% rate of fracture shortening of more than 2 cm. Wu[9] noted that patients who had shortening were the same ones who did not achieve union with dynamization. Given these results, Wu[9] advocated against routine dynamization and instead advocated bone grafting for fractures that did not heal after more than 7 months. Several other studies noted the risk of shortening with dynamization, and it appears that the fracture pattern is the greatest factor in determining whether a fracture will shorten after dynamization.[9,13,14] Spiral, long oblique, and comminuted fractures are at greatest risk for shortening.[4,13] In addition, there is a risk of rotational malunion after removal of interlocking screws in rotationally unstable fracture patterns. Interlocking screws help to maintain both length and rotational stability. Removing them can promote fracture collapse and subsequent healing and also can allow the fracture site to rotate.

The current study evaluated 35 instances of delayed union and nonunion of tibial and femoral shaft fractures treated with nail dynamization and found that dynamization was successful in promoting union in 53% of cases. This finding is similar to previously published reports of both femoral and tibial dynamization.[4,8,9,11,12] Previous studies are summarized in **Table 1**. Earlier studies reported complications such as rotational deformity or shortening of the fracture, but the current study included only 1 patient who had a rotational deformity through the nonunion, and this was treated successfully with an exchange nail. In contrast to previous reports, the current study did not find a similar rate of shortening. One reason for this finding may be selective use of dynamization because none of the fractures that were treated with dynamization had distraction of more than 1 cm at the time of surgery.

A secondary goal of this study was to identify variables that would predict either success or failure of nail dynamization. Callus diameter and open fracture were identified as factors that correlated with success and failure, respectively, of dynamization. Callus diameter also was used as a measure of the biologic environment at the fracture site, based on the assumption that increased callus diameter correlates with increased healing potential and a more favorable vascular and biologic environment. These findings emphasize the importance of blood supply to fracture healing. Open fractures devitalize much of the bone and the surrounding soft tissue that are vitally important to fracture healing. Most notably, in the current study, the lack of callus formation, which likely correlates with poor regional blood supply, was very predictive of failure of nail dynamization.

Another important factor to consider in nail dynamization is the decreased direct costs compared with exchange nailing. This study found a greater than $10,000 difference in costs between nail dynamization and exchange nailing. If fracture healing can be achieved in more than half of patients, with a savings of more than $10,000 per case, the financial implications favor dynamization as a first-line treatment over exchange nailing. Extrapolating from the difference in direct costs between dynamization and exchange nail-

ing, dynamization would need to be only 19% effective in creating successful union to offer a cost savings over exchange nailing as the primary treatment of patients with delayed union and nonunion. In addition, this finding does not factor in the likely increased indirect savings associated with dynamization through its lower morbidity rates, so these results likely underreport the cost savings with dynamization.

This study examined several other variables to determine whether they could be predictive of successful dynamization, but it did not determine whether smoking, medication use, medical comorbidities, fracture pattern, implant size, or time to dynamization played a role in predicting successful dynamization. This is likely the result of the small size of the study and the relatively healthy, nonsmoking population.

Despite its limitations, this study provides information that can help to predict success after nail dynamization. Although dynamization may not be indicated in all patients with delayed union or nonunion, its low morbidity, quick recovery, and ease of operation make it preferable to bone grafting, exchange nailing, or compression plating.

Conclusion

The current findings suggest that nail dynamization can be an effective method to promote healing in both femoral and tibial shaft delayed union and nonunion. It was effective in 54% of the patients in the current study. This rate is similar to previously published reports. Risk factors for failure of dynamization include pathologic fracture, open fracture, and atrophic delayed union or nonunion. The current series of 34 patients is larger than any previously reported study. The efficacy of nail dynamization in promoting fracture healing, combined with its low morbidity and decreased costs compared with bone grafting, exchange nailing, and compression plating, makes it a preferable option for the first step in the select treatment of femoral and tibial delayed union and nonunion.

References

1. Canadian Orthopaedic Trauma Society. Nonunion following intramedullary nailing of the femur with and without reaming: results of a multicenter randomized clinical trial. *J Bone Joint Surg Am.* 2003; 85(11):2093-2096.
2. Winquist RA, Hansen ST Jr, Clawson DK. Closed intramedullary nailing of femoral fractures: a report of five hundred and twenty cases. *J Bone Joint Surg Am.* 1984; 66(4):529-539.
3. Wolinsky PR, McCarty E, Shyr Y, Johnson K. Reamed intramedullary nailing of the femur: 551 cases. *J Trauma.* 1999; 46(3):392-399.
4. Chalidis BE, Petsatodis GE, Sachinis NC, Dimitriou CG, Christodoulou AG. Reamed interlocking intramedullary nailing for the treatment of tibial diaphyseal fractures and aseptic nonunions: can we expect an optimum result? *Strategies Trauma Limb Reconstr.* 2009; 4(2):89-94.
5. Kempf I, Grosse A, Beck G. Closed locked intramedullary nailing: its application to comminuted fractures of the femur. *J Bone Joint Surg Am.* 1985; 67(5):709-720.
6. Hanks GA, Foster WC, Cardea JA. Treatment of femoral shaft fractures with the Brooker-Wills interlocking intramedullary nail. *Clin Orthop Relat Res.* 1988; 226:206-218.
7. Klemm KW, Börner M. Interlocking nailing of complex fractures of the femur and tibia. *Clin Orthop Relat Res.* 1986; 212:89-100.
8. Basumallick MN, Bandopadhyay A. Effect of dynamization in open interlocking nailing of femoral fractures: a prospective randomized comparative study of 50 cases with a 2-year follow-up. *Acta Orthop Belg.* 2002; 68(1):42-48.
9. Wu CC. The effect of dynamization on slowing the healing of femur shaft fractures after interlocking nailing. *J Trauma.* 1997; 43(2):263-267.
10. Tigani D, Fravisini M, Stagni C, Pascarella, R, Boriani S. Interlocking nail for femoral shaft fractures: is dynamization always necessary? *Int Orthop.* 2005; 29(2):101-104.
11. Wu CC, Shih CH. Effect of dynamization of a static interlocking nail on fracture healing. *Can J Surg.* 1993; 36(4):302-306.
12. Wu CC, Chen WJ. Healing of 56 segmental femoral shaft fractures after locked nailing: poor results of dynamization. *Acta Orthop Scand.* 1997; 68(6):537-540.
13. Lynch JR, Taitsman LA, Barei DP, Nork SE. Femoral nonunion: risk factors and treatment options. *J Am Acad Orthop Surg.* 2008; 16(2):88-97.
14. Gelalis ID, Politis AN, Arnaoutoglou CM, et al. Diagnostic and treatment modalities in nonunions of the femoral shaft: a review. *Injury.* 2012; 43(7):980-988.
15. Vécsei V, Häupl J. The value of dynamic adjustment in locking intramedullary nailing [in German]. *Aktuelle Traumatol.* 1989; 19(4):162-168.
16. Shih KS, Hsu CC, Hsu TP. A biomechanical investigation of the effects of static fixation and dynamization after interlocking femoral nailing: a finite element study. *J Trauma Acute Care Surg.* 2012; 72(2):E46-E53.
17. Pihlajamäki HK, Salminen ST, Böstman OM. The treatment of nonunions following intramedulllary nailing of femoral shaft fractures. *J Orthop Trauma.* 2002; 16(6):394-402.